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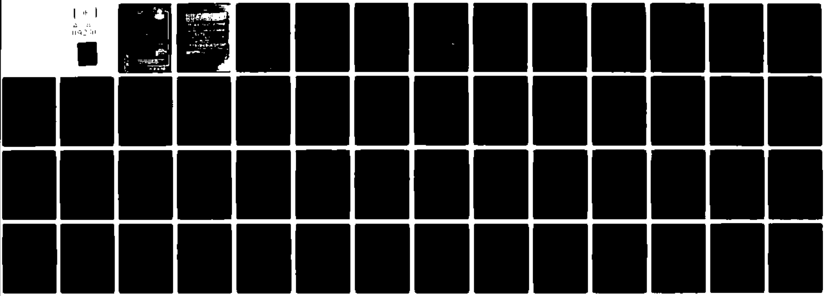

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BOILER EFFICIENCY AND EMISSIONS TESTING

USING REFUSE-DERIVED FUEL (RDF) AND COAL

WRIGHT-PATTERSON AFB, OHIO 45433

AUGUST 1982

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is an evaluation of (1) boiler performance, i.e., boiler efficiency and combustion properties; and (2) environmental emissions, i.e., electrostatic precipitator performance, particulate emissions (size and resistivity), gaseous emissions (SOx, NOx, CO and HC) and trace organics; while burning the following three fuel combinations at maximum boiler capacity; (1) 100% coal, (2) 40/60 refuse-derived fuel (RDF) to coal; and (3) 100% RDF.

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USAF OCCUPATIONAL AND ENVIRONMENTAL

HEALTH LABORATORY

Brooks AFB, Texas 78235

Boiler Efficiency and Emission Testing

Using Refuse-Derived Fuel (RDF) and Coal

Wright-Patterson AFB, Ohio 45433

August 1982

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PREFACE

In February 1982, the USAF Occupational and Environmental Health Laboratory (USAF OEHL) and Air Force Engineering and Services Center (AFESC) contracted Research Triangle Institute (RTI) to test and evaluate the burning of various mixtures of coal and Teledyne-produced densified refuse-derived fuel (RDF). Entropy Environmentalists was subcontracted by RTI to perform a survey under Contract No. F33615-80-D-4000, Order No. 19, to determine boiler efficiency, electrostatic precipitator (ESP) performance, and air emissions while burning RDF, on steam boiler No. 4 in Building 770 at Wright-Patterson Air Force Base (WPAFB). The project monitor for RTI was Dr Joseph Sickles and the USAF OEHL project monitor was Captain Robart Bauer.

REPORT CERTIFICATION
By Entropy Environmentalists

The sampling and analysis performed for this report was carried out under my direction and supervision.

Date July 2, 1982 Signature Barry F. Rudd

Barry F. Rudd

I have reviewed all testing details and results in this test report and hereby certify that the test report is authentic and accurate.

Date July 2, 1982 Signature D. James Grove

D. James Grove, P. E.

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*Additional information can be found in a separately bound appendix maintained at the U.S. Air Force Occupational and Environmental Health Laboratory/ECA and Air Force Engineering Services Center/RD.

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INTRODUCTION AND OBJECTIVES

The U.S. Air Force Occupational and Environmental Health Laboratory, Brooks AFB TX, HQ Air Force Engineering and Services Center, Tyndall AFB FL and the Research Triangle Institute, Research Triangle Park NC conducted a test program to aid in evaluation of the desirability of using refuse-derived fuel (RDF) as a primary or supplementary fuel in military boilers and to aid the Air Force in the design of future RDF and multifuel boilers by highlighting potential needs or shortcomings in emissions control and material handling systems, duct size, and boiler thermal and economic efficiency. In support of this aim, stationary source sampling was performed in February 1982 by Entropy Environmentalists, Inc., on steam boiler #4 at building 770, Wright-Patterson AFB OH.

The purpose of the testing was to quantify the differences in the boiler pollutant emissions, precipitator efficiency, and boiler thermal efficiency resulting from varying the fuel type burned in the boiler. Table 1 presents the specific test purposes and the associated methodology used. A sampling log with the dates, fuel types, specific objectives, locations, and run/ sample number is given in Table 2. A list of the test coordinators, observers, and other participants, and their affiliation is presented in Table 3.

Results of the test program are presented in the "Summary of Results" section in four subsections: 1) a summary of all the results, which includes the results in the two summary

TABLE 1

TESTING PURPOSES AND METHODOLOGY

Purpose	Method Employed
Determination of Particulate Emissions	EPA Method 5
Determination of Sulfur Dioxide Emissions	EPA Method 8
Determination of Nitrogen Oxides Emissions	EPA Method 7
Determination of Total Gaseous Nonmethane Organic Emissions (as Carbon)	EPA Method 25
Determination of Flyash Particle Size	In situ Cascade Impactor Tests
Determination of Flyash Resistivity	ASME PTC 28-1965, Paragraph 4.05
Determination of Flue Gas Yaw Angle	EPA Method 1, Section 2.4
Determination of Boiler Efficiency	ASME PTC 4.1, Section 4

TABLE 2

TESTING LOG

Date	Fuel	Testing Purpose	Location (@ ESP)	Run/ Sample Nos.
22-23 Feb	40% RDF/ 60% Coal Mix	Particulate Emissions	Inlet	1-3
		Particulate and Sulfur Dioxide Emissions	Outlet	4-6
		Particle Sizing	Inlet Outlet	S1-S2 S3-S4
		Nitrogen Oxides Emissions	Outlet	1-12
		Total Nonmethane Organics	Outlet	1-3
		Flue Gas Yaw Angle	Inlet Outlet	1 2
		Boiler Efficiency	-	1
24 Feb	100% RDF	Particulate Emissions	Inlet	7-9
		Particulate and Sulfur Dioxide Emissions	Outlet	10-12
		Particle Sizing	Inlet Outlet	S5-S6 S7-S8
		Nitrogen Oxides Emissions	Outlet	13-24
		Total Nonmethane Organics	Outlet	4-6
		Flue Gas Yaw Angle	Inlet Outlet	3 4
		Boiler Efficiency	-	2
26 Feb	100% Coal	Particulate Emissions	Inlet	13-15
		Particulate and Sulfur Dioxide Emissions	Outlet	16-18
		Particle Sizing	Inlet Outlet	S9-S10 S11-S12
		Nitrogen Oxides Emissions	Outlet	25-36
		Total Nonmethane Organics	Outlet	7-9
		Boiler Efficiency	-	3

TABLE 3

TEST COORDINATORS, OBSERVERS AND OTHER PARTICIPANTS

Name	Affiliation
Capt Robart W. Bauer	USAF OEHL/ECA, Brooks AFB TX
Mr. Thomas E. Shoup	2750 ABW/DEEX, WPAFB OH
1Lt Paul C. Vitucci	HQ AFESC/RDVA, Tyndall AFB FL
Mr. S. James Ryckman Jr	2750 ABW/DEEX, WPAFB OH
Mr. Brian E. Swaidan	Naval Civil Engineering Laboratory, Port Hueneme CA
Mr. Clyde Farris	Plant Superintendent, Bldg 770 WPAFB OH
Sgt Tommy Thompson	USAF OEHL/ECA, Brooks AFB TX
Mr. Barry F. Rudd	Entropy Environmentalists, Inc. Research Triangle Park NC
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subsections, 2) summaries of the emissions and precipitat
efficiency testing, 3) a summary of the boiler operating efficiency testing, and 4) a discussion of the results and conclusions.

A cursory presentation of boiler operational characteristics and an air flow schematic are given in the "Process Descripition and Operation" section. Testing methodology is discussed in the "Sampling and Analytical Procedures" section.

SUMMARY OF RESULTS

The average pollutant emission results, average precipitator efficiency results and average boiler operating efficiency results for each of the three fuel conditions, as well as the particle sizing, flow angle and resistivity tests results, are presented in Table 4.

Due to the difference in the fuel types being burned, the maximum steam loading obtainable for each fuel mix was not the same; since the boiler emissions and efficiency are affected by the loading, care must be used in comparing the results.

The "Boiler Emissions and Precipitator Efficiencies" and "Boiler Efficiency" subsections present the individual run-by-run summaries for each of the two main test objectives at each of the three fuel type test conditions. A third subsection, "Conclusions and Observations," presents a discussion and interpretation of the results. The first subsection, "Boiler Emissions and Precipitator Efficiencies," also presents the F-factor values, the results from the flyash resistivity measurements, and the flue gas flow angle data summaries.

The 40% RDF-60% coal ratio in Table 4 was calculated using the average ultimate heating values for coal and RDF in conjunction with the heating value obtained for the RDF/coal mixtures. Using this method, the estimated percent of coal making up the RDF/coal mixtures averaged 60.2% dry, by weight. Samples 1, 2, and 3, were 64.0%, 49.9%, and 66.7% coal, respectively.

TABLE 4

AVERAGE RESULTS PER FUEL CONDITION

	40% RDF/ 60% Coal	100% RDF	100% Coal
Boiler Data			
Steam Load, lb/hr	115,000	97,000	146,000
Efficiency, %	82.7	75.5	75.5
Precipitator Data			
Particulate Concent.	- - - grains per dscf - - -		
Precipitator Inlet	0.361	0.337	0.472
Precipitator Outlet	0.011	0.009	0.014
Collection Eff., %	97.0	97.4	97.0
Emissions to Atmosphere	- pounds per Million Btu -		
Particulate	0.026	0.024	0.029
Sulfur Dioxide	0.847	0.372	0.926
Nitrogen Oxides as NO_2	0.506	0.584	0.680
Total Nonmethane Organics as Carbon	0.261	0.177	0.103
	- - ppm dry by volume - -		
Sulfur Dioxide	315	116	392
Nitrogen Oxides as NO_2	261	248	397
Total Nonmethane Organics as Carbon	519	295	231
Flyash Resistivity, ohm-cm	4.7×10^7	4.9×10^7	4.6×10^7
Yaw Angle of Flue Gas, degrees			
Precipitator Inlet	7.4	14	-
Precipitator Outlet	7.0	5.6	-
Particle Size, mass median dia.*			
Precipitator Inlet, microns	25	3.0	17
Precipitator Outlet, microns	1.1	2.1	3.6

*Taken from log-probability plot

Boiler Emissions and Precipitator Efficiencies

The particulate emissions and precipitator efficiencies are summarized on a run-by-run basis for each of the three fuel conditions in Table 5. Table 6 presents run-by-run emissions concentrations summaries of the sulfur dioxide, nitrogen oxides and total nonmethane organics testing. Particle sizing runs are summarized in Tables 7 through 9. Tables 10 through 15 present individual run results for the inlet particulate runs and the outlet particulate and sulfur dioxide runs. Individual nitrogen oxide sample results are in Tables 16 through 18.

Fuel samples were taken periodically from each of the four feeders for all nine outlet particulate and sulfur dioxide runs. Ultimate and heating value analyses were performed on each composite fuel sample. The F-factor values calculated from those results and subsequently used in calculating heat inputs and emissions are given in Table 19.

It should be noted that the RDF/Coal mixture samples were difficult to process for analysis due to differences in consistency of the two fuels. Theoretically, the calculated equivalent RDF/coal mixture F-factor would be between the F-factor values for coal and RDF; however, the actual RDF/coal mixture F-factors calculated from the ultimate analyses were greater than the F-factor for either coal or RDF on two of the three samples. The theoretical average F-factor calculated from the average coal and RDF F-factors and the 40%-60% RDF/coal mix ratio differs by 2%.

TABLE 5

PARTICULATE EMISSION CONCENTRATIONS AND PRECIPITATOR COLLECTION EFFICIENCIES

Simultaneous Runs	Particulate Concen. Gr/DSCF Inlet	Particulate Concen. Gr/DSCF Outlet	Collection Efficiency	Particulate Concen.* Lb/MBtu Outlet
		40% RDF/60% Coal		
1, 4	0.3055	0.0063	97.9	0.0144
2, 5	0.3997	0.0145	96.4	0.0337
3, 6	0.3788	0.0122	96.8	0.0285
Avg	0.3613	0.0110	97.0	0.0255
		100% RDF		
7, 10	0.3839	0.0110	97.1	0.0307
8, 11	0.2744	0.0059	97.8	0.0164
9, 12	0.3522	0.0096	97.2	0.0258
Avg	0.3368	0.0088	97.4	0.0243
		100% Coal		
13, 16	0.5190	0.0171	96.7	0.0376
14, 17	0.4292	0.0129	97.0	0.0267
15, 18	0.4665	0.0125	97.3	0.0233
Avg	0.4716	0.0142	97.0	0.0292

*Ohio Particulate Emission Standard is .10 lbs/MBTU

TABLE 6

OUTLET GASEOUS CONCENTRATIONS

SO Run	Fuel	-- Parts Per Million, Dry by Volume -- SO_2	NO_x	Total Nonmethane Organics
4	40% RDF/ 60% Coal	305.3	244.4	682.0
5		317.1	257.5	366.1
6		322.2	282.3	510.3
Avg		314.9	261.4	519.5
10	100% RDF	128.2	264.4	300.4
11		109.0	236.7	281.1
12		111.6	241.6	304.9
Avg		116.3	247.6	295.5
16	100% Coal	357.9	410.4	200.2
17		362.1	424.2	319.9
18		456.3	356.4	172.8
Avg		392.1	397.0	231.0

TABLE 7

PARTICLE SIZING TESTS SUMMATION, RDF/COAL

Precipitator Inlet

RUN S1		RUN S2	
AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.	AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.
15.23	36.6	15.00	50.3
9.55	31.2	9.41	46.0
6.38	26.2	6.28	39.0
4.42	21.9	4.35	33.5
2.79	17.0	2.75	26.7
1.43	13.4	1.41	22.2
0.87	10.0	0.86	18.9
0.59	7.2	0.58	14.7

Precipitator Outlet

RUN S3		RUN S4	
AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.	AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.
14.18	91.3	14.34	97.5
8.91	81.7	9.01	95.0
5.94	72.6	6.01	92.4
4.11	61.9	4.16	90.1
2.60	49.2	2.63	87.4
1.33	40.9	1.35	81.4
0.81	31.0	0.82	59.7
0.55	20.2	0.55	35.9

TABLE 8

PARTICLE SIZING TESTS SUMMATION, 100% RDF

Precipitator Inlet

RUN S5		RUN S6	
AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.	AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.
15.21	83.1	15.23	65.9
9.54	75.8	9.55	60.5
6.37	64.6	6.38	54.3
4.41	59.1	4.41	49.2
2.79	51.4	2.79	43.1
1.43	45.4	1.43	38.1
0.87	40.4	0.87	31.7
0.59	33.8	0.59	25.5

Precipitator Outlet

RUN S7		RUN S8	
AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.	AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.
14.04	93.2	14.54	90.6
8.82	83.1	9.13	84.2
5.88	74.7	6.09	73.8
4.07	62.2	4.22	64.1
2.58	52.6	2.66	54.4
1.32	39.4	1.36	44.0
0.80	25.3	0.83	32.2
0.54	16.9	0.56	22.8

TABLE 9

PARTICLE SIZING TESTS SUMMATION, 100% COAL

Precipitator Inlet

RUN S9		RUN S10	
AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.	AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.
14.42	42.9	14.07	52.4
9.06	36.4	8.84	43.0
6.04	27.1	5.89	33.0
4.18	21.2	4.08	24.6
2.64	14.9	2.58	16.3
1.35	10.1	1.32	10.6
0.82	7.0	0.80	7.3
0.55	4.5	0.54	4.6

Precipitator Outlet

RUN S11		RUN S12	
AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.	AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.
14.67	85.8	14.74	87.4
9.21	72.3	9.25	75.7
6.15	62.4	6.18	62.8
4.25	55.1	4.28	53.4
2.69	42.3	2.70	42.5
1.38	24.1	1.38	32.5
0.84	9.1	0.84	22.0
0.57	0.7	0.57	13.5

TABLE 10

PARTICULATE TESTS SUMMARY OF RESULTS

Boiler #4, Precipitator Inlet, RDF/Coal

	1	2	3
RUN DATE	02/22/82	02/22/82	02/23/82
TEST TRAIN PARAMETERS:			
VOLUME OF DRY GAS SAMPLED, SCF*	50.098	60.091	62.189
PERCENT ISOKINETIC	102.5	105.5	105.7
STACK PARAMETERS:			
TEMPERATURE, DEG. F	502	524	526
AIR FLOW RATES SCFM*, DRY	32,289	37,632	38,869
ACFM, WET	64,400	77,053	79,625
METHOD 5 TEST RESULTS:			
CATCH, MILLIGRAMS	991.9	1,556.5	1,526.6
GRAINS PER DSCF*	0.3055	0.3997	0.3788
LBS PER HOUR	84.56	128.94	126.21

* 68 Deg. F. - 29.92 in. Hg.

TABLE 11

PARTICULATE & SULFUR DIOXIDE TESTS SUMMARY OF RESULTS

Boiler #4 ESP Outlet, RDF/Coal

	4	5	6
RUN DATE	02/22/82	02/22/82	02/23/82
TEST TRAIN PARAMETERS:			
VOLUME OF DRY GAS SAMPLED, SCF*	37.121	38.937	40.709
PERCENT ISOKINETIC	101.9	92.4	92.8
STACK PARAMETERS:			
TEMPERATURE, DEG. F	475	497	504
AIR FLOW RATES SCFM*, DRY	34,466	39,875	41,484
ACFM, WET	66,804	78,895	83,193
PERCENT EXCESS AIR	57.8	59.1	57.9
HEAT INPUT, MBTU/HR	129.7	147.7	151.7
METHOD 5, PARTICULATES:			
CATCH, MILLIGRAMS	15.2	36.7	32.1
GRAINS PER DSCF*	0.0063	0.0145	0.0122
LBS PER HOUR	1.87	4.97	4.33
LBS PER MILLION BTU	0.0144	0.0337	0.0285
METHOD 8, SULFUR DIOXIDE:			
CATCH, MILLIGRAMS	853.9	930.4	988.3
PPM, DRY	305.3	317.1	322.2
LBS PER HOUR	104.87	126.04	133.22
LBS PER MILLION BTU	0.8083	0.8534	0.8779

* 68 Deg. F. - 29.92 in. Hg.

TABLE 12

PARTICULATE TESTS SUMMARY OF RESULTS

Boiler #4, Precipitator Inlet, 100% RDF

	7	8	9
RUN DATE	02/24/82	02/24/82	02/24/82
TEST TRAIN PARAMETERS:			
VOLUME OF DRY GAS SAMPLED, SCF*	69.210	63.329	62.868
PERCENT ISOKINETIC	108.5	109.8	109.1
STACK PARAMETERS:			
TEMPERATURE, DEG. F	551	539	538
AIR FLOW RATES SCFM*, DRY	42,109	38,085	38,074
ACFM, WET	90,273	81,997	81,315
METHOD 5 TEST RESULTS:			
CATCH, MILLIGRAMS	1,721.7	1,126.1	1,434.6
GRAINS PER DSCF*	0.3839	0.2744	0.3522
LBS PER HOUR	138.56	89.58	114.93

* 68 Deg. F. - 29.92 in. Hg.

TABLE 13

PARTICULATE & SULFUR DIOXIDE TESTS SUMMARY OF RESULTS

Boiler #4 ESP Outlet, 100% RDF

	10	11	12
RUN DATE	02/24/82	02/24/82	02/24/82
TEST TRAIN PARAMETERS:			
VOLUME OF DRY GAS SAMPLED, SCF*	39.324	39.871	44.441
PERCENT ISOKINETIC	94.9	103.8	105.8
STACK PARAMETERS:			
TEMPERATURE, DEG. F	505	496	490
AIR FLOW RATES SCFM*, DRY	45,039	41,736	39,724
ACFM, WET	92,075	85,972	80,570
PERCENT EXCESS AIR	94.5	86.2	83.8
HEAT INPUT, MBTU/HR	138.4	128.8	126.6
METHOD 5, PARTICULATES:			
CATCH, MILLIGRAMS	28.0	15.3	27.6
GRAINS PER DSCF*	0.0110	0.0059	0.0096
LBS PER HOUR	4.24	2.12	3.26
LBS PER MILLION BTU	0.0307	0.0164	0.0258
METHOD 8, SULFUR DIOXIDE:			
CATCH, MILLIGRAMS	379.8	327.5	373.7
PPM, DRY	128.2	109.0	111.6
LBS PER HOUR	57.54	45.35	44.19
LBS PER MILLION BTU	0.4158	0.3521	0.3491

* 68 Deg. F. - 29.92 in. Hg.

TABLE 14

PARTICULATE TESTS SUMMARY OF RESULTS

Boiler #4, Precipitator Inlet, 100% Coal

	13	14	15
RUN DATE	02/26/82	02/26/82	02/26/82
TEST TRAIN PARAMETERS:			
VOLUME OF DRY GAS SAMPLED, SCF*	50.979	51.798	40.492
PERCENT ISOKINETIC	107.1	108.1	105.8
STACK PARAMETERS:			
TEMPERATURE, DEG. F	556	566	535
AIR FLOW RATES SCFM*, DRY	47,630	47,936	35,373
ACFM, WET	99,294	99,911	71,881
METHOD 5 TEST RESULTS:			
CATCH, MILLIGRAMS	1,714.6	1,440.6	1,224.1
GRAINS PER DSCF*	0.5190	0.4292	0.4665
LBS PER HOUR	211.91	176.35	141.45

* 68 Deg. F. - 29.92 in. Hg.

TABLE 15

PARTICULATE & SULFUR DIOXIDE TESTS SUMMARY OF RESULTS

Boiler #4 ESP Outlet, 100% Coal

	16	17	18
RUN DATE	02/26/82	02/26/82	02/26/82
TEST TRAIN PARAMETERS:			
VOLUME OF DRY GAS SAMPLED, SCF*	55.990	55.087	45.283
PERCENT ISOKINETIC	103.5	102.1	101.5
STACK PARAMETERS:			
TEMPERATURE, DEG. F	533	539	512
AIR FLOW RATES SCFM*, DRY	51,192	51,020	42,190
ACFM, WET	104,487	104,062	83,697
PERCENT EXCESS AIR	55.9	44.9	32.0
HEAT INPUT, MBTU/HR	199.7	211.4	193.6
METHOD 5, PARTICULATES:			
CATCH, MILLIGRAMS	62.1	46.1	36.6
GRAINS PER DSCF*	0.0171	0.0129	0.0125
LBS PER HOUR	7.51	5.65	4.51
LBS PER MILLION BTU	0.0376	0.0267	0.0233
METHOD 8, SULFUR DIOXIDE:			
CATCH, MILLIGRAMS	1,510.0	1,502.9	1,556.8
PPM, DRY	357.9	362.1	456.3
LBS PER HOUR	182.62	184.12	191.87
LBS PER MILLION BTU	0.9146	0.8711	0.9910

* 68 Deg. F. - 29.92 in. Hg.

TABLE 16

NITROGEN OXIDES TESTS SUMMARY

Boiler #4 Precipitator Outlet, RDF/Coal Mixture

SAMPLE NUMBER	1	2	3	4
DATE	2/22/82	2/22/82	2/22/82	2/22/82
VOLUME OF GAS SAMPLED MLS*, DRY	1992.2	1980.6	1964.7	1894.3
NITROGEN DIOXIDE (NO_2) RESULTS:				
MICROGRAMS ABSORBED	867.8	935.5	935.5	918.8
PPM BY VOLUME, DRY	228.0	247.0	249.0	253.6
POUNDS PER HOUR	56.31	60.99	61.49	62.63
POUNDS PER MILLION BTU	0.434	0.470	0.474	0.483

SAMPLE NUMBER	5	6	7	8
DATE	2/22/82	2/22/82	2/22/82	2/22/82
VOLUME OF GAS SAMPLED MLS*, DRY	1969.5	1921.5	1942.7	1891.7
NITROGEN DIOXIDE (NO_2) RESULTS:				
MICROGRAMS ABSORBED	1035.8	1052.5	969.0	751.8
PPM BY VOLUME, DRY	275.0	286.4	260.8	207.8
POUNDS PER HOUR	78.57	81.83	74.51	59.37
POUNDS PER MILLION BTU	0.532	0.554	0.505	0.402

TABLE 16 (continued)

NITROGEN OXIDES TESTS SUMMARY

Boiler #4 Precipitator Outlet, RDF/Coal Mixture

SAMPLE NUMBER	9	10	11	12
DATE	2/23/82	2/23/82	2/23/82	2/23/82
VOLUME OF GAS SAMPLED MLS*, DRY	1955.8	1968.5	2003.4	1878.7
NITROGEN DIOXIDE (NO_2) RESULTS:				
MICROGRAMS ABSORBED	1136.0	968.9	1035.8	1069.2
PPM BY VOLUME, DRY	303.7	257.4	270.3	297.6
POUNDS PER HOUR	90.27	76.50	80.36	88.45
POUNDS PER MILLION BTU	0.595	0.504	0.530	0.583

TABLE 17

NITROGEN OXIDES TESTS SUMMARY

Boiler #4 Precipitator Outlet, 100% RDF

SAMPLE NUMBER	13	14	15	16
DATE	2/24/82	2/24/82	2/24/82	2/24/82
VOLUME OF GAS SAMPLED MLS*, DRY	1812.3	1808.2	1805.1	1745.0
NITROGEN DIOXIDE (NO_2) RESULTS:				
MICROGRAMS ABSORBED	952.2	852.0	935.5	885.4
PPM BY VOLUME, DRY	274.7	246.4	271.0	265.3
POUNDS PER HOUR	88.66	79.51	87.45	85.62
POUNDS PER MILLION BTU	0.641	0.575	0.632	0.619

SAMPLE NUMBER	17	18	19	20
DATE	2/24/82	2/24/82	2/24/82	2/24/82
VOLUME OF GAS SAMPLED MLS*, DRY	1856.4	1889.5	1875.9	1764.6
NITROGEN DIOXIDE (NO_2) RESULTS:				
MICROGRAMS ABSORBED	902.1	751.8	885.4	801.9
PPM BY VOLUME, DRY	254.1	208.1	246.8	237.6
POUNDS PER HOUR	75.98	62.22	73.80	71.06
POUNDS PER MILLION BTU	0.590	0.483	0.573	0.552

TABLE 17 (continued)

NITROGEN OXIDES TESTS SUMMARY

Boiler #4 Precipitator Outlet, 100% RDF

SAMPLE NUMBER	21	22	23	24
DATE	2/24/82	2/24/82	2/24/82	2/24/82
VOLUME OF GAS SAMPLED MLS*, DRY	1949.2	1985.7	1969.8	1834.3
NITROGEN DIOXIDE (NO_2) RESULTS:				
MICROGRAMS ABSORBED	918.8	902.1	902.1	852.0
PPM BY VOLUME, DRY	246.5	237.6	239.5	242.9
POUNDS PER HOUR	70.15	67.61	68.16	69.13
POUNDS PER MILLION BTU	0.599	0.577	0.582	0.590

TABLE 18

NITROGEN OXIDES TESTS SUMMARY

Boiler #4 Precipitator Outlet, 100% Coal

SAMPLE NUMBER	25	26	27	28
DATE	2/26/82	2/26/82	2/26/82	2/26/82
VOLUME OF GAS SAMPLED MLS*, DRY	2015.0	2110.9	1966.7	2125.2
NITROGEN DIOXIDE (NO_2) RESULTS:				
MICROGRAMS ABSORBED	1670.6	1603.8	1503.5	1670.6
PPM BY VOLUME, DRY	433.5	397.3	399.7	411.0
POUNDS PER HOUR	159.02	145.72	146.62	150.77
POUNDS PER MILLION BTU	0.796	0.730	0.734	0.755

SAMPLE NUMBER	29	30	31	32
DATE	2/26/82	2/26/82	2/26/82	2/26/82
VOLUME OF GAS SAMPLED MLS*, DRY	2028.7	1933.6	1975.2	1976.7
NITROGEN DIOXIDE (NO_2) RESULTS:				
MICROGRAMS ABSORBED	1603.8	1737.4	1603.8	1470.1
PPM BY VOLUME, DRY	413.4	469.9	424.6	388.9
POUNDS PER HOUR	151.12	171.76	155.20	142.16
POUNDS PER MILLION BTU	0.715	0.813	0.734	0.673

TABLE 18 (continued)

NITROGEN OXIDES TESTS SUMMARY

Boiler #4 Precipitator Outlet, 100% Coal

SAMPLE NUMBER	33	34	35	36
DATE	2/26/82	2/26/82	2/26/82	2/26/82
VOLUME OF GAS SAMPLED MLS*, DRY	1971.0	1966.2	1970.2	1925.9
NITROGEN DIOXIDE (NO_2) RESULTS:				
MICROGRAMS ABSORBED	1403.3	1236.2	1369.9	1303.1
PPM BY VOLUME, DRY	372.3	328.8	363.6	353.8
POUNDS PER HOUR	112.54	99.38	109.91	106.95
POUNDS PER MILLION BTU	0.581	0.513	0.568	0.552

TABLE 19

F-FACTORS FROM FUEL ANALYSES

Outlet Part. & Sulfur Dioxide Run No.	Sample Number	Fuel Mix	F-Factor* DSCF/MBtu
4	1	40% RDF/ 60% Coal	9,990
5	2		10,076
6	3		10,281
10	4	100% RDF	9,903
11	5		10,232
12	6		10,090
16	7	100% Coal	9,715
17	8		9,840
18	9		9,822

* Calculated from Ultimate Analysis Data from Tables 23-25 using the equation below:

F-FACTOR EXAMPLE FOR SAMPLE #1, COLLECTED 2/22/82

$$F = \frac{((3.64*\%H)+(1.53*\%C)+(0.57*\%S)+(0.14*\%N)-(0.46*\%O))*10^6}{GCV}$$

$$F = \frac{(3.64(5.77)+1.53(70.68)+0.57(0.77)+0.14(1.55)-0.46(14.80))(10^6)}{12,312}$$

F= 9,990 DSCF/MBtu

Flue Gas Flow Angle and Flyash Resistivities

Flow angle tests were performed during the first and second fuel mix runs (40% RDF/60% Coal and 100% RDF) to determine the degree of air flow turbulence (yaw angle) at the inlet and outlet sampling locations. An average yaw angle of 10.7 degrees at the inlet and 6.3 degrees at the outlet was measured; since the EPA maximum allowable yaw angle is 10 degrees per test, no significant effect on the results at either location is expected.

Resistivity tests were performed in the laboratory on the inlet flyash samples under conditions similar to those encountered in the inlet duct. Results of these tests can be seen in Table 20.

TABLE 20

INLET FLYASH RESISTIVITIES

Condition	Reading	Resistivity
40% RDF/60% Coal Mix	1	4.7×10^{7}
	2	4.7×10^{7}
	Average	4.7×10^{7}
100% RDF	1	4.9×10^{7}
	2	4.8×10^{7}
	Average	4.9×10^{7}
100% Coal	1	4.5×10^{7}
	2	4.6×10^{7}
	Average	4.6×10^{7}

Boiler Efficiency

The thermal efficiency of boiler #4 was determined concurrently with the emissions testing using a modified version of the input-output method as detailed in ASME Power Test Code 4.1. Three 96 minute runs were performed for each fuel mix condition. The results are presented in Table 21.

Total heat inputs to the boiler were the sum of the available heat from the fuel (calculated by the F-factor method) and the various heat credits; the heat inputs for each run are given in Table 22. The heat credits considered were the sensible heats in the incoming air and in the water in the air, the sensible heat in the fuel, and the heat introduced by the auxiliary fans; of these, only the two sensible heats in the incoming air were significant.

The heat output was determined by subtracting the heat content of the feedwater from the heat content of the steam produced. This data was taken from charts showing a continuous readout of both steam volume and pressure. The steam was assumed to be saturated at 388 psi; the feedwater temperature remained constant at 165 degrees F.

Each day the boiler was operated at the maximum load possible. Note that the maximum load obtained while burning 100% RDF was only 65% of the maximum load obtained with 100% coal. Also note that the excess air during the 100% RDF runs averaged twice the excess air of the 100% coal runs.

TABLE 21

BOILER EFFICIENCIES

Boiler #4, Building 770

Fuel Type	Run No.	Steam Load lbs/hr	Excess Air percent	Heat Rates MBtu Per Hour Input	Heat Rates MBtu Per Hour Output	Operating Efficiency percent
40% RDF/ 60% Coal	4	102,000	58	134.5	109.4	81.3
	5	118,000	59	153.3	126.6	82.5
	6	124,000	58	157.5	132.9	84.4
					Average	82.7
100% RDF	10	102,000	95	144.8	109.4	75.6
	11	94,000	86	134.7	100.8	74.8
	12	94,000	84	132.2	100.8	76.2
					Average	75.5
100% Coal	16	147,700	56	206.8	158.4	76.6
	17	149,500	45	218.5	160.6	73.5
	18	142,000	32	199.5	152.3	76.3
					Average	75.5

Notes

Run numbers correspond to outlet particulate-sulfur dioxide runs

Input = F-factor heat input and heat credits

Output = (pounds of steam per hour) x (Btu per pound of steam - Btu per pound of water)

Efficiency = (output/input) x 100%

TABLE 22

BOILER HEAT INPUTS

Outlet Part. & Sulfur Dioxide Run No.	Heat Input, Million Btu/Hour From* Fuel	Sensible Heat	Total
4	129.7	4.8	134.5
5	147.7	5.6	153.3
6	151.7	5.8	157.5
10	138.4	6.4	144.8
11	128.8	5.9	134.7
12	126.6	5.6	132.2
16	199.7	7.1	206.8
17	211.4	7.1	218.5
18	193.6	5.9	199.5

* Calculated using F-factor Method

TABLE 23

ULTIMATE FUEL ANALYSIS

RDF/Coal Mixture Fuel Analysis

	--Sample 1--		--Sample 2--		--Sample 3--	
	As Recd	Dry	As Recd	Dry	As Recd	Dry
Moisture, %	8.96	-	9.26	-	7.31	-
Ash, %	5.85	6.43	9.34	10.29	4.58	4.94
Sulfur, %	0.70	0.77	0.50	0.55	0.60	0.65
Btu/Lb	11208	12312	10433	11498	11560	12472
Carbon	64.34	70.68	60.34	66.50	68.82	74.25
Hydrogen	5.25	5.77	5.15	5.68	5.14	5.54
Nitrogen	1.41	1.55	1.41	1.55	1.26	1.36
Oxygen	13.49	14.80	14.00	15.43	12.29	13.26
Softening Temp of Ash, Deg F	2,165		2,465		2,430	

TABLE 24

ULTIMATE FUEL ANALYSIS

100% RDF Fuel Analysis

	--Sample 4--		--Sample 5--		--Sample 6--	
	As Recd	Dry	As Recd	Dry	As Recd	Dry
Moisture, %	11.35	-	11.87	-	12.07	-
Ash, %	8.04	9.06	9.62	10.92	7.28	8.28
Sulfur, %	0.15	0.17	0.11	0.12	0.12	0.13
Btu/Lb	7257	8186	7638	8667	7861	8940
Carbon	42.94	48.44	44.55	50.55	45.30	51.52
Hydrogen	5.64	6.36	6.17	7.00	6.33	7.20
Nitrogen	0.37	0.42	0.35	0.40	0.32	0.37
Oxygen	31.51	35.55	27.33	31.01	28.58	32.50
Softening Temp of Ash, Deg F	<2,000		2,240		2,310	

TABLE 25

ULTIMATE FUEL ANALYSIS

100% Coal Fuel Analysis

	--Sample 7--		--Sample 8--		--Sample 9--	
	As Recd	Dry	As Recd	Dry	As Recd	Dry
Moisture, %	6.92	-	6.76	-	6.50	-
Ash, %	5.34	5.73	5.01	5.37	4.52	4.84
Sulfur, %	0.68	0.73	0.69	0.74	0.74	0.79
Btu/Lb	13356	14349	13457	14433	13494	14433
Carbon	74.26	79.78	75.66	81.15	75.82	81.09
Hydrogen	5.06	5.44	5.08	5.45	5.10	5.46
Nitrogen	1.47	1.58	1.47	1.58	1.51	1.62
Oxygen	6.27	6.74	5.33	5.71	5.81	6.20
Softening Temp of Ash, Deg F	>2,800		2,770		2,690	

Conclusions and Observations

Conclusions and observations can be grouped into two general categories: 1) the effect of the different fuel mixtures on precipitator efficiency and pollutant emissions and 2) the effect of the different fuel mixtures on material handling systems (including boiler firing chamber maintenance) and boiler efficiency.

1) From Table 4 it is apparent that the type of fuel mixture fired has little or no effect on the particulate collection efficiency of the precipitator. This conclusion is reinforced by the fact that the flyash resistivity remained essentially constant for the ash from all three fuel mixtures. However, the steam flow rate for the 100% RDF tests was only 66% of the steam rate for the 100% coal tests while steam load for the RDF/coal tests was 77% of that of the 100% coal tests. The collection efficiencies may or may not be similar if the steam flow rate is held constant for all fuel mixtures. In any case, the particulate emissions are well below the limits set by the Ohio EPA (.10 lbs/MBTU), and any differences may be of little consequence. No U.S. EPA emission standards apply to this boiler since it generates less than 250 MBTU/hr. It is recommended that a constant steam flow rate be among the objectives of any further test programs.

Sulfur dioxide emissions were considerably lower using 100% RDF as opposed to 100% coal. The RDF/coal mixture showed some reduction of sulfur dioxide emissions but not as dramatic a reduction as seen with 100% RDF. This is understandable in that the RDF is shown by ultimate fuel analysis to contain a lower percentage of sulfur and sulfur compounds than the coal.

The nitrogen oxides emissions for the 100% coal tests were considerably higher than those of the 100% RDF and RDF/coal mixture tests. Since higher temperature (among other factors) increases nitrogen oxide production, this suggests that the combustion temperatures were indeed higher while firing 100% coal. This could not be verified due to the lack of necessary instrumentation.

The differences in nonmethane organic emissions between the three fuel conditions are more difficult to interpret. The 100% coal tests showed the lowest emissions while the 100% RDF tests showed an increase in emissions of approximately 70%. The RDF/coal mixture tests, which presumably would show an intermediate level of emissions, in fact revealed emissions 50% higher than the 100% RDF tests. The implication is that unknown thermodynamic conditions and/or stoichometric relationships in the boiler were affecting the nonmethane organic emissions.

Particle size analysis results showed essentially what would be expected. The mass median particle diameter at the precipitator inlet during the 100% RDF tests was 3.0 microns which is lower than expected. However, since the excess air in the boiler was much higher with this fuel than during the tests with the other two fuels, the higher excess air would have led to more complete combustion and, thereby, to smaller particles exiting the firing chamber.

2) Using 100% RDF led to one problem associated with its low density and heat content, and another which was probably a result of its metal content.

The first problem was the inability of the material handling system to convey a large enough amount of fuel to the boiler to maintain a normal (approximately 120 to 140 thousand pounds per hour) steam flow rate. The sheer bulk of the RDF overtaxed the fuel feed conveyers and, incidentally, the counter mechanism for quantifying the amount of fuel fed. The RDF also created a large volume of fibrous dust which led to an increase in housekeeping efforts.

The second major problem is that the RDF (from visual inspection and conversations with boiler maintenance personnel) caused greater than normal slag buildup on boiler tubes and walls. This would probably lead, in the long term, to a drop in boiler efficiency and an increase in downtime for firing chamber maintenance.

It appears from the data that boiler efficiency increased when the RDF/coal mixture was fired. Again, it must be taken into consideration that the steam flow rate varied between the three fuel conditions. Additionally, boiler instrumentation was inadequate to evaluate steam quality, i.e., temperature, pressure, and degree of saturation. These parameters could be expected to change under different steam flow rates and fuel conditions. Due to the lack of steam data, steam quality had to

be assumed to be constant even though it most likely was not. The data seem to show that there are both advantages and disadvantages to the use of RDF as boiler fuel. It is recommended that these data be used in conjunction with other past or future data to determine if the fuel can be used to improve the economic and environmental performance of medium sized boilers.

PROCESS DESCRIPTION AND OPERATION

Building 770 at Wright-Patterson AFB uses five boilers to produce steam for building heat and other small processes. The testing in this report was performed on boiler #4.

The boiler is a Keeler rotograte overfire unit rated at 150,000 pounds per hour of steam. The design steam pressure is 600 pounds per square inch, but was operated at approximately 385 pounds per square inch during the testing. The electrostatic precipitator is a dual chamber unit designed by Precipitair.

As shown in Figure 1, the flue gases from the combustion chamber are ducted to a dust collector, electrostatic precipitator, air preheater and induced draft fan before entering the common duct which conducts the gases to the stack and the atmosphere.

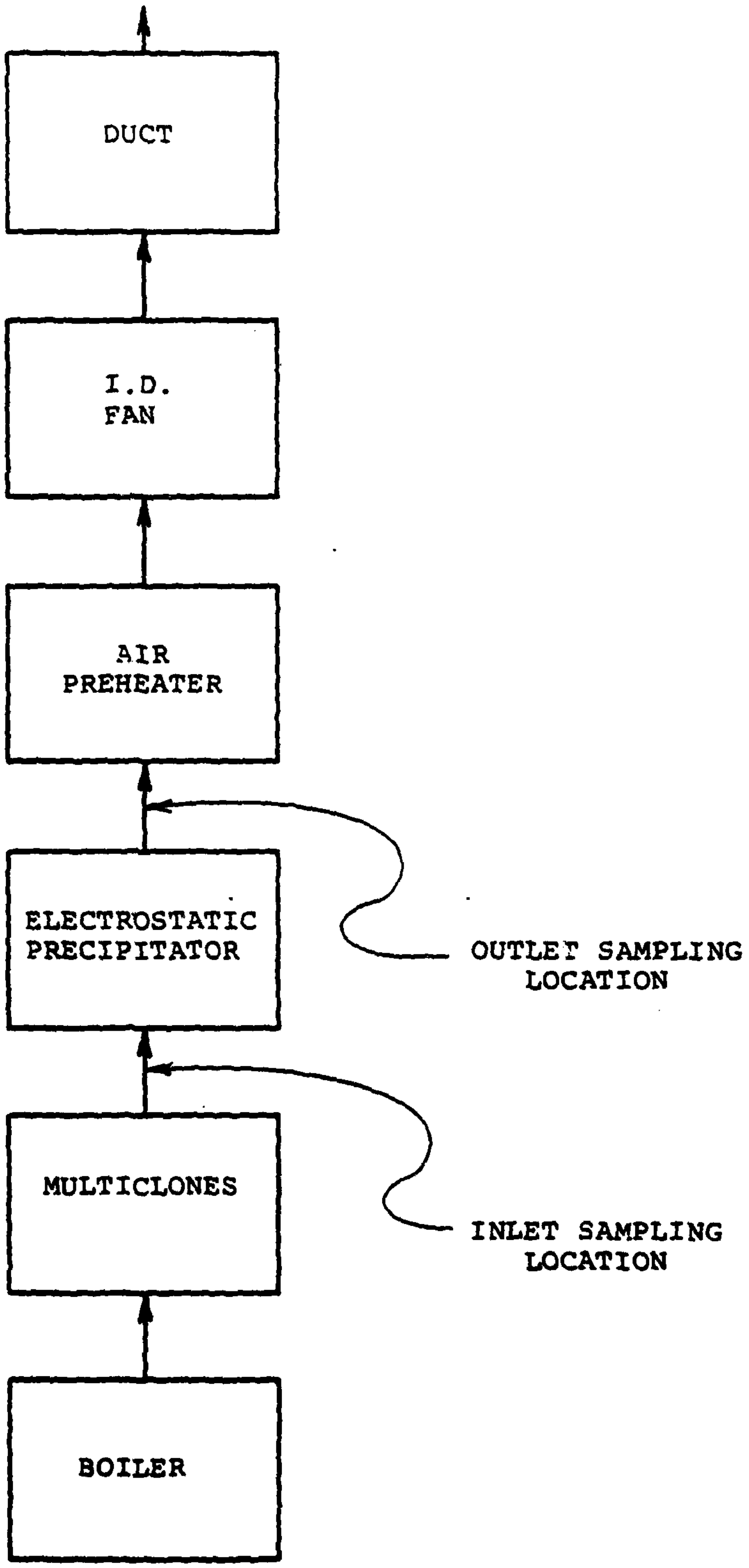


FIGURE 1. AIR FLOW SCHEMATIC SHOWING SAMPLING LOCATIONS

SAMPLING AND ANALYTICAL PROCEDURES

All sampling and analytical procedures used were those generally recommended by the United States Environmental Protection Agency (U.S. EPA), the Ohio Environmental Protection Agency and the American Society of Mechanical Engineers (ASME). Details of the equipment and procedures used are described in Appendix V, which is extracted from the Federal Register, August 18, 1977.

The number and locations of the sampling points were determined using EPA Method 1. The inlet and outlet ducts cross sections were each divided into 48 equal areas, i.e., 12 points on each of the four traverse axes, as shown in Figures 2 and 3 for the inlet duct and Figures 4 and 5 for the outlet duct. The centroid of each equal area was sampled for two minutes for a net run time of 96.

Velocity measurements were made according to EPA Method 2. The flue gas composition and molecular weight were determined using EPA Method 3 criteria. Particulate emissions at the inlet were determined using EPA Method 5 procedures. Outlet particulate and sulfur dioxide emissions determinations followed the procedures outlined in combined EPA Methods 5 and 8. Nitrogen oxides emissions determinations used EPA Method 7 criteria. EPA Method 25 was used in determining total gaseous nonmethane organic emissions. Particle sizing was performed

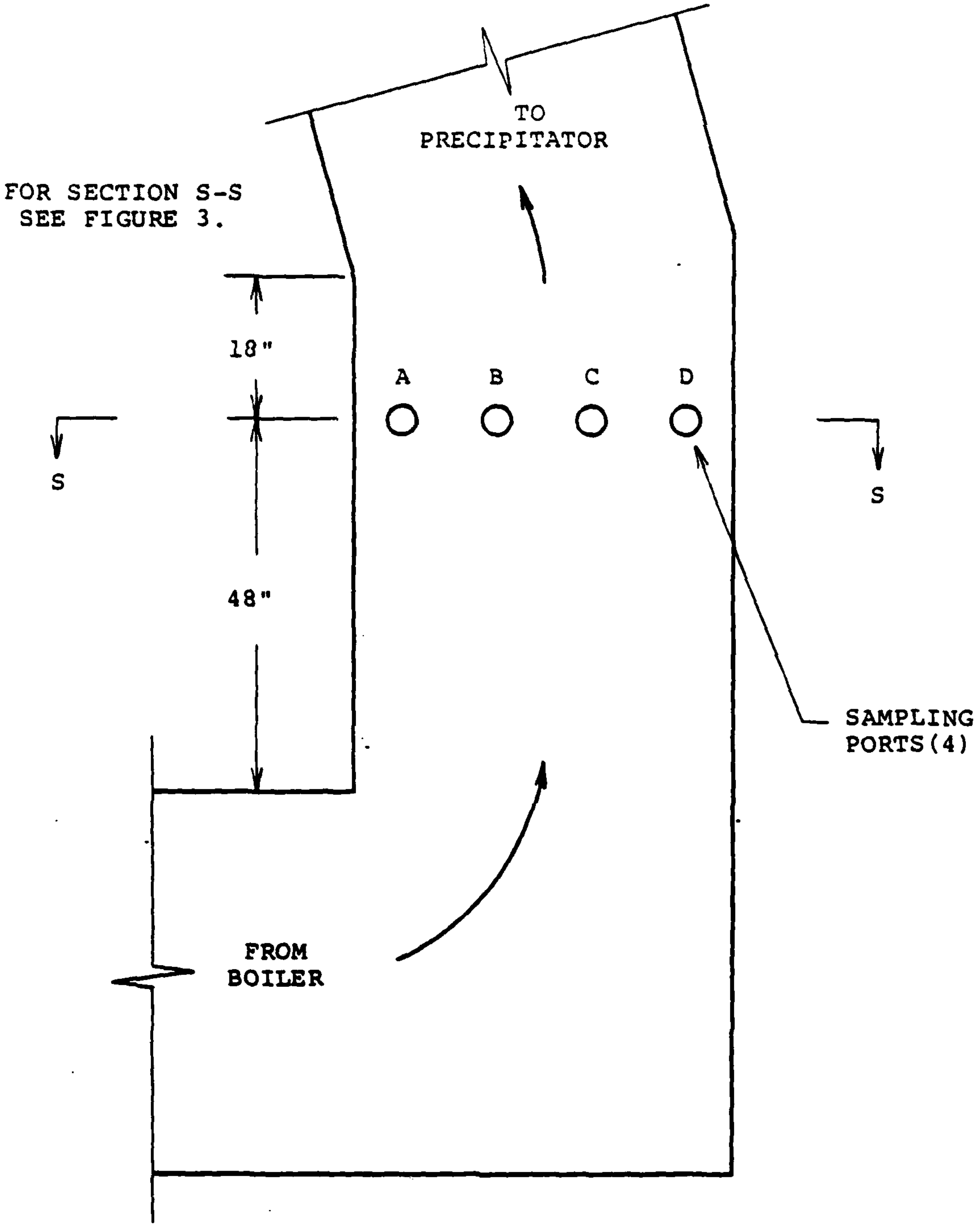


FIGURE 2. INLET DUCT DIMENSIONS AND SAMPLING PORT LOCATIONS

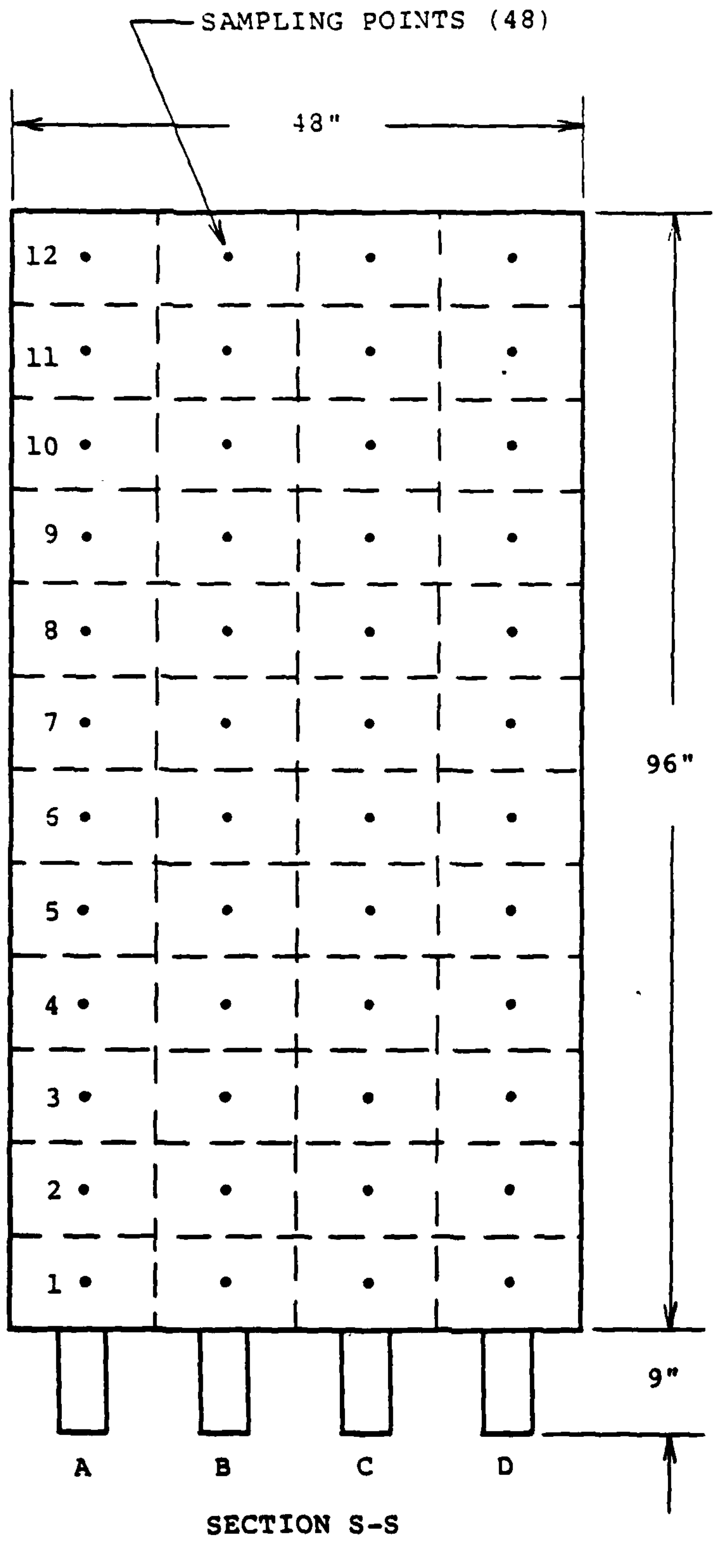


FIGURE 3. INLET DUCT CROSS SECTION SHOWING EQUAL AREA DIVISIONS AND SAMPLING POINT LOCATIONS

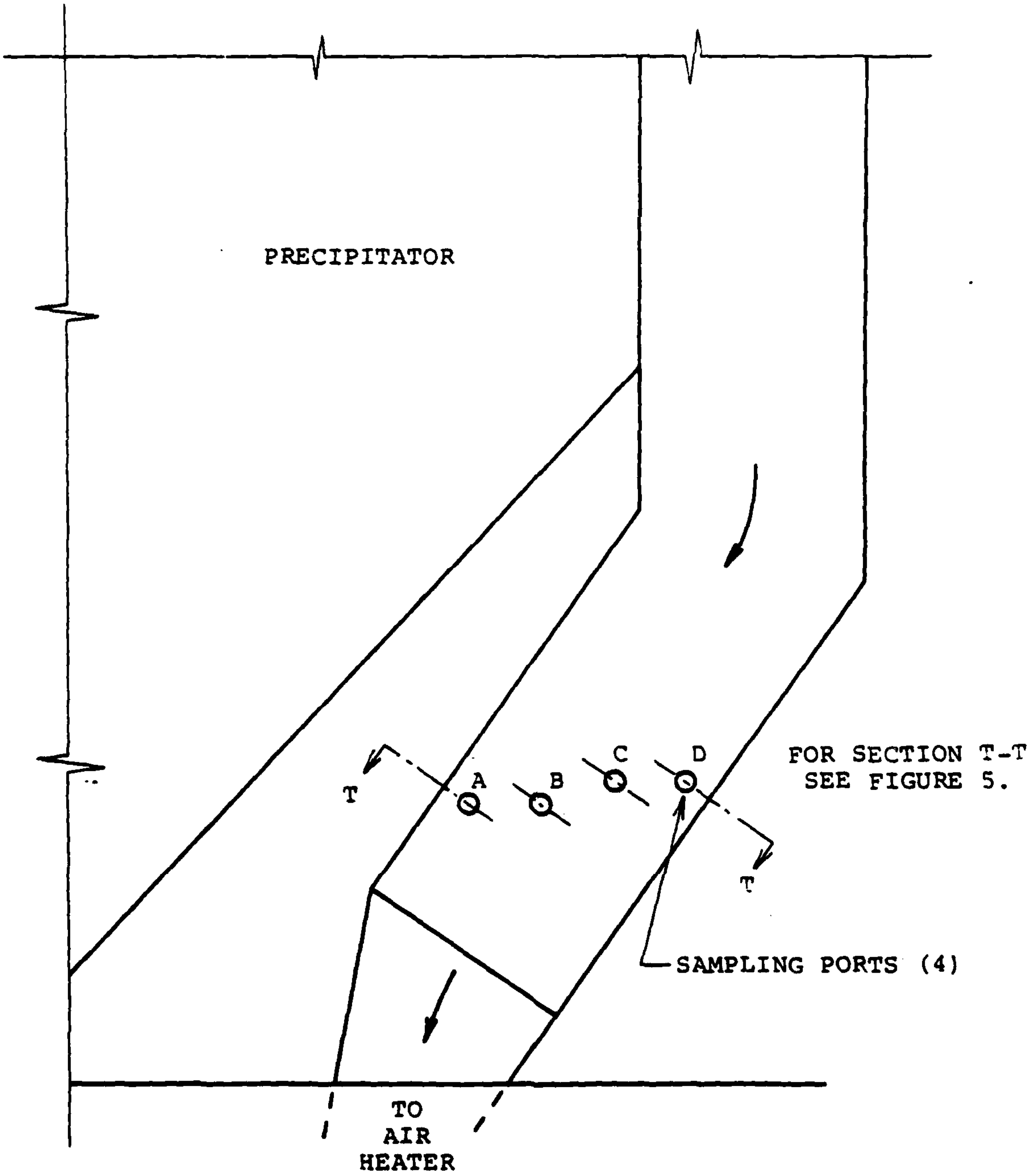
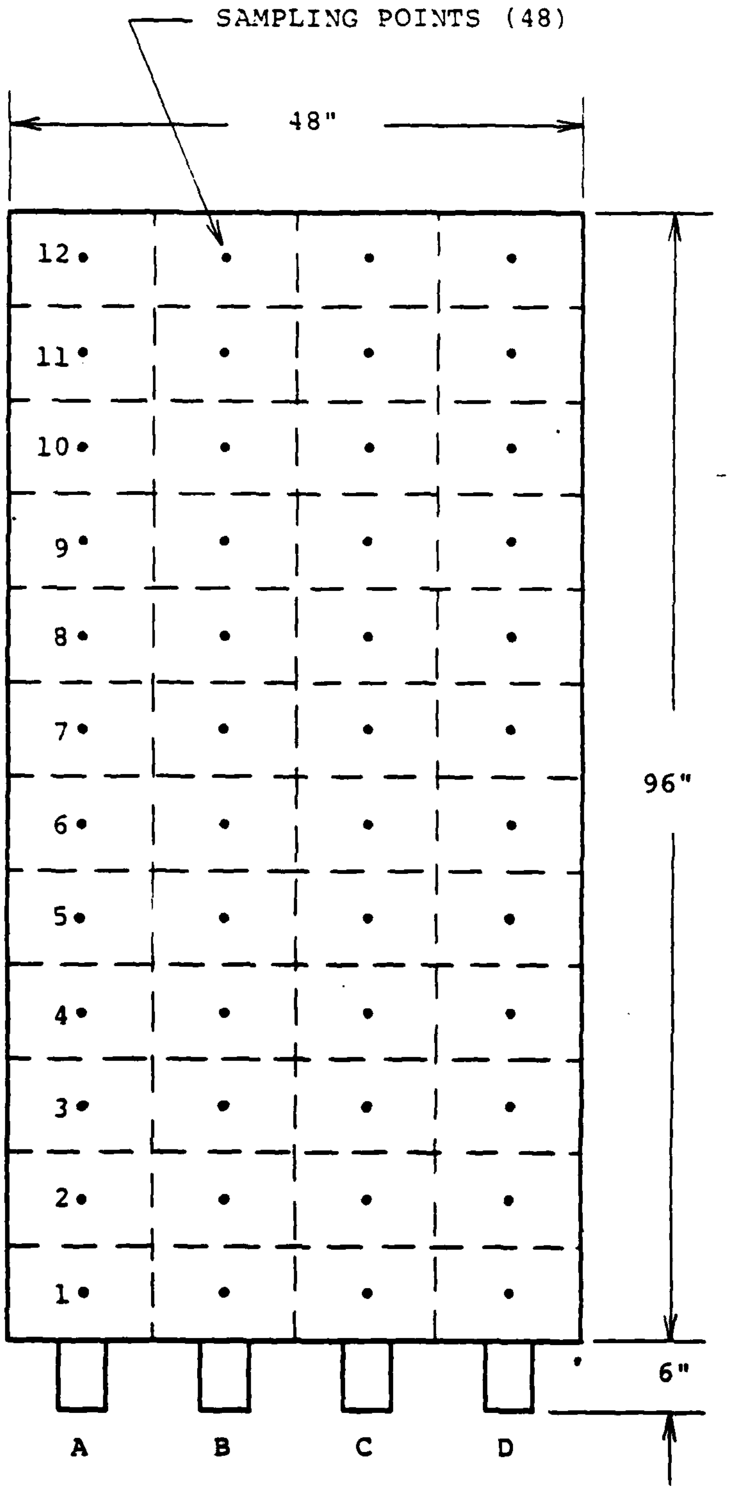


FIGURE 4. OUTLET DUCT CONFIGURATION SHOWING SAMPLING PORT LOCATIONS



SECTION T-T

FIGURE 5. OUTLET DUCT CROSS SECTION SHOWING EQUAL AREA DIVISIONS AND SAMPLING POINT LOCATIONS

using a cascade impactor sampling head attached to an EPA Method 5 probe end.

Boiler efficiency tests were performed at each condition according to ASME Power Test Code 4.1, section 4, which is the input-output method.

Flyash resistivity tests were performed according to paragraph 4.05 of ASME Power Test Code 28-1965. The flyash samples for resistivity measurements were collected at the precipitator inlet following EPA Method 5 procedures. For each condition, the filter catches for the three runs performed were combined to make one sample. In the laboratory, the test cell was filled with flyash and heated to 500 degrees F to simulate inlet duct conditions. Two readings were taken for each sample.

The F-factor value used in the calculations was determined using the ultimate analyses of the fuel samples.

All sampling equipment used was manufactured by Nutech Corporation, Andersen Samplers, Inc., or Entropy Environmentalists, Inc.